

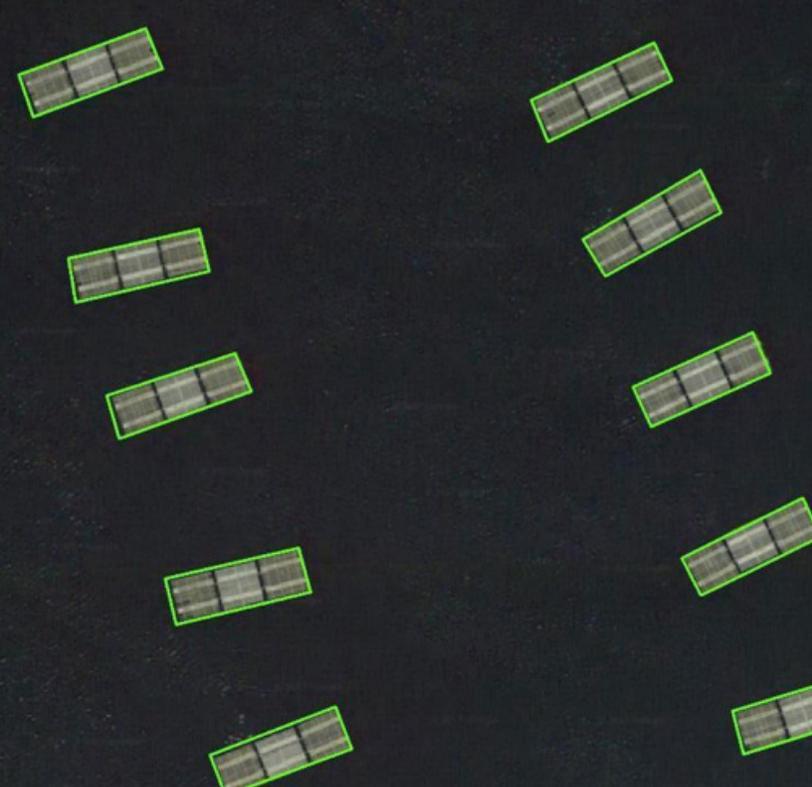


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# Salmon Habitat Status and Trends: Monitoring Protocols



**July 2019**

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration  
National Marine Fisheries Service  
Northwest Fisheries Science Center

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# **Salmon Habitat Status and Trends: Monitoring Protocols**

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Northwest Fisheries Science Center

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## Executive Summary

In 2014 and 2015, we began a habitat status and trend monitoring program for the Puget Sound Chinook, Hood Canal Summer Chum, and Puget Sound Steelhead Evolutionarily Significant Units (ESUs), and in 2018 expanded the program to the Oregon Coast Coho Salmon ESU. The purpose of this monitoring program is to provide consistent habitat data for evaluating trends in the habitat listing factor at each 5-year status review for the listed ESUs. This monitoring program is satellite- and aerial-imagery-based, covering large river, floodplain, delta, and nearshore habitats. As part of the monitoring program, we developed protocols for delineating floodplain, delta, and nearshore boundaries, and measuring habitat features and calculating monitoring metrics.

Guided by lidar and aerial photography, we delineated boundaries of the geomorphic floodplains and deltas, which were defined as the relatively level surfaces extending laterally from the bankfull channel at bankfull elevation. We mapped the floodplain and delta analysis areas to encompass 1) habitat areas that have been lost or degraded through past land use changes, and 2) habitat areas that may be restored in the future. This helps assure that our land cover metrics accurately reflect the current land cover status of floodplains and deltas, and that habitat losses or gains (especially from restoration actions) will be detected by the monitoring program. The floodplain analysis area also encompasses large river features. We delineated the nearshore analysis area by creating a 200-m inland buffer for each shoreline segment to calculate land cover and riparian metrics. On the seaward side, we digitized all overwater structures within the nearshore in order to establish a baseline status dataset.

We developed 22 protocols for monitoring land use and habitat changes in large rivers, floodplains, deltas, and the nearshore. Protocols for the nine land cover metrics (percent forest, agriculture and developed area in floodplains, deltas, and nearshore buffer) were based on 30-m resolution satellite data (from NOAA's Coastal Change Analysis Program, or C-CAP). The other 13 metrics were manually digitized using aerial imagery and oblique photos to avoid classification errors inherent in automated image processing. We calculated the 13 monitoring metrics in order to document changes in large rivers, floodplains, deltas, and the nearshore, which included braid and side-channel length ratios, braid and side-channel node densities, area of wood jams and backwaters (alcoves), tidal channel area and edge habitat length, tidal channel node density, tidal barriers, riparian buffer width, and overwater structures in the nearshore.

## Introduction

In 2014 and 2015, we began a habitat status and trend monitoring program for the Puget Sound Chinook, Hood Canal Summer Chum, and Puget Sound Steelhead Evolutionarily Significant Units (ESUs), covering large river, floodplain, delta, and nearshore habitats. The purpose of this monitoring program is to provide consistent habitat data for evaluating trends in the habitat listing factor at each 5-year status review for the listed ESUs. As part of the monitoring program, we developed protocols for delineating floodplain, delta, and nearshore boundaries, and measuring habitat features and calculating monitoring metrics. In 2018 we expanded the monitoring program to the Oregon Coast Coho salmon ESU. Funding was reduced at the end of 2018. In this report, we summarize the protocols for delineating analysis area boundaries, and for measuring habitat features and calculating habitat metrics.

# Delineation of Floodplain, Delta, and Nearshore Boundaries

Prior to monitoring habitat features, the analysis area boundaries for floodplains, deltas and the nearshore must be delineated. The analysis area boundaries are intended to encompass the area within which habitat features will be measured, and land cover status and trends will be monitored. To the extent possible, we map the historical boundary of floodplains and deltas so that we capture potentially restorable habitats and accurately represent current land cover status. Similarly, we delineate the nearshore boundaries to capture historical habitat features and current land cover status and shoreline type. In the following sections we describe our protocols for mapping these analysis area boundaries.

## Floodplain Boundaries

For each river basin monitored, we manually digitize a floodplain boundary layer that represents the geomorphic floodplain. We define the geomorphic floodplain as the relatively level surface extending laterally from the edge of the bankfull channel at the bankfull channel elevation. This area is typically frequently flooded (at least every few years) but we include areas within the floodplain that are currently disconnected by levees, roads, and other developments. While low terraces may also be partially inundated during floods with large return intervals (e.g., a 50-yr or 100-yr flood), those areas are outside the geomorphic floodplain and are excluded from the analysis. The large river analysis area is contained within the floodplain analysis area.

Within each river, we map the floodplain extent upstream of delta boundaries, including all river reaches with drainages greater than 50 km<sup>2</sup> (which typically have a bankfull width of 15-20 meters), excluding areas upstream of natural or man-made salmon migration barriers. In areas where the floodplain is much wider than the river channel (e.g., Samish River), we limit the floodplain extent to a 1-km buffer from the bankfull edge to avoid creating an unnecessarily large analysis area.

Floodplain boundaries are manually digitized using aerial imagery and lidar where available, and using aerial imagery and the 10-m National Elevation Dataset (NED) where lidar is not available. This allows the exclusion of low terraces that have little potential for development of salmon habitat, and inclusion of all areas where floodplain habitat is visible. When using lidar, we manually digitize the floodplain boundary at the toe of hill slopes or terraces (Figure 1). Terraces are distinguished from the floodplain by manually measuring the elevation of areas surrounding the main channel on the lidar digital elevation model (DEM) (terraces are typically ~5 meters or more above the main channel). Where no lidar coverage is available, we digitize floodplain boundaries to include all active channels and floodplain areas using Google aerial and satellite imagery and the Arc2Earth extension (Arc2Earth, 2017). For consistency, we digitize all floodplain boundaries at the same map scale (e.g., we use a scale of 1:1,000 for all digitized features).

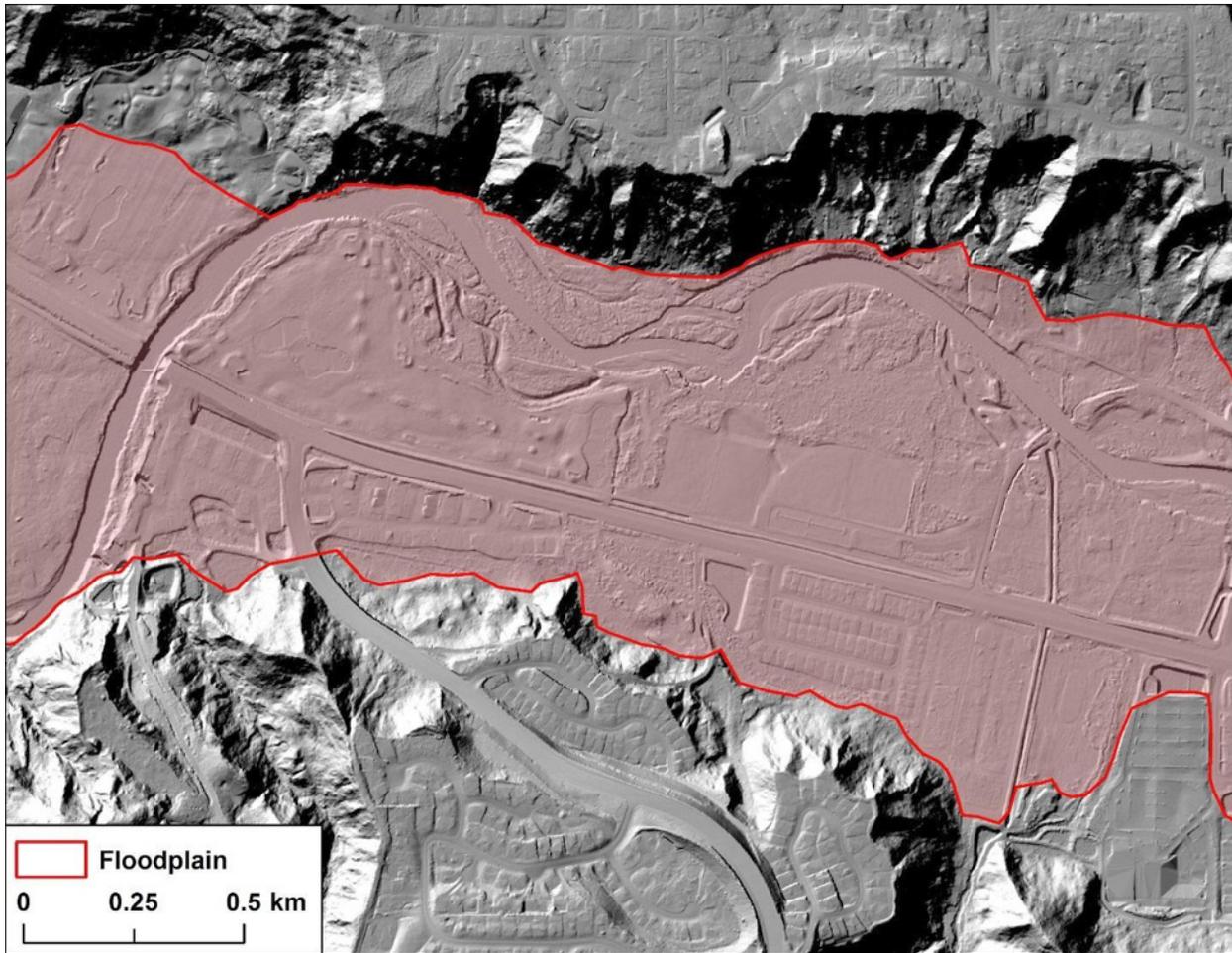


Figure 1. Example of floodplain boundary placed at the toe of terraces with elevation of 5 meters or more above river main channel elevation (Cedar River near Renton, Washington).

Once the floodplain layer is digitized, we assign floodplain polygons to biogeographic areas to facilitate analysis of habitat status and trends among Major Population Groups (MPGs) or Biogeographic Units. It is also helpful to create reach breaks at apparent changes in channel pattern, geomorphic valley type, or land cover class. This allows analysis of differences in habitat status or trends among geomorphic settings and land cover classes (e.g., Beechie et al. 2017, Stefankiv et al. 2019). For example, in Puget Sound we stratified reaches by geomorphic process domain as defined in Collins and Montgomery (2011), which includes glacial valleys, post-glacial valleys, mountain valleys, and canyons. We also stratified reaches by land cover class (forested, agriculture, developed) using NOAA's Coastal Change Analysis Program (C-CAP) 2010 data. This allowed us to evaluate differences in habitat attributes among geomorphic valley types and land use classes.

The floodplain polygon layer attribute table includes a unique reach identifier number, and any stratification attributes that are assigned to each polygon. For example, the attribute table for Puget Sound floodplains includes:

- Reach\_ID: Unique reach identifier
- Ck\_MPG: Chinook major population groups, which include Strait of Georgia, Whidbey Basin, Central/South Basin, Hood Canal, and Strait of Juan de Fuca
- Stl\_MPG: Steelhead major population groups, which include Northern Cascades, South-Central Cascades, and Olympic
- VT: Geomorphic valley types which include glacial valleys (GL), post-glacial valleys (PGL), canyons (C), and mountain valleys (MTN)
- LC: Dominant land cover, developed using C-CAP 2010 data, which we aggregated into forest/wetland (F), agriculture (Ag), and developed (D) classes

## Delta Boundaries

As with the floodplains, delta boundaries are digitized as polygon features using 2015/2016 Google aerial and satellite images and lidar. The upriver or landward boundaries of deltas are guided by the two-year or 50% tidal exceedance boundary (Brophy et al. 2019, Lanier et al. 2014). The landward boundaries are digitized to capture all areas likely to have contained tidal marsh or tidal channel features historically, including areas that have been blocked or filled (Figure 2). Areas that appear to be filled, and are therefore too high to be mapped within the current delta polygon based on their lidar elevation, are identified and digitized based on their appearance on topographic maps and/or aerial photographs. We exclude parts of the 50% exceedance polygon that are confined to distributary and main channels upstream of the delta boundary (Figure 2).

The seaward boundaries of the deltas are digitized at the edge of vegetated marshes within the geomorphic delta fan, or—where rivers flow into a bay—at the mouth of the bay. For deltas without bays, the seaward edge of the delta boundary polygon feature extends to the seaward extent of densely vegetated marsh surfaces where vegetation covers nearly 100% of the surface. Where vegetation is very patchy or at low density, a second delta boundary feature called “Low-Density Marsh” can be digitized (Figure 3). These features capture the boundary of low-density vegetated marshes that may represent disappearing marsh surfaces (e.g., from erosion or subsidence) or new marsh surfaces forming along the delta fringe (e.g., from deposition and colonization). Larger vegetated islands that fall within the geomorphic delta fan are also included and are designated as either a marsh island or low-density marsh island. Where dikes have been breached along the seaward edge of the delta, the delta boundary polygon is digitized along the seaward edge of the previous dike footprint. In some cases, the area contained within the restoration site may be devoid of vegetation or have low-density vegetation due to subsidence of the land surface prior to dike removal (Figure 4). For consistency in digitizing features, all delta boundaries should be digitized at a scale of 1:1,000.





Figure 3. Low-density marsh boundary at the seaward edge of the delta boundary in the Skagit River delta. The area within the red polygon boundary contains low-density marsh vegetation vs. the landward edge of the high-density marsh vegetation, that has a more definitive edge.



Figure 4. Example of a restoration project that breached and removed portions of a dike that was at the seaward edge of the vegetated marsh boundary. The area interior of the previous dike footprint is digitized as the delta boundary, while the low density marsh area seaward of the previous dike footprint was digitized as low density marsh.



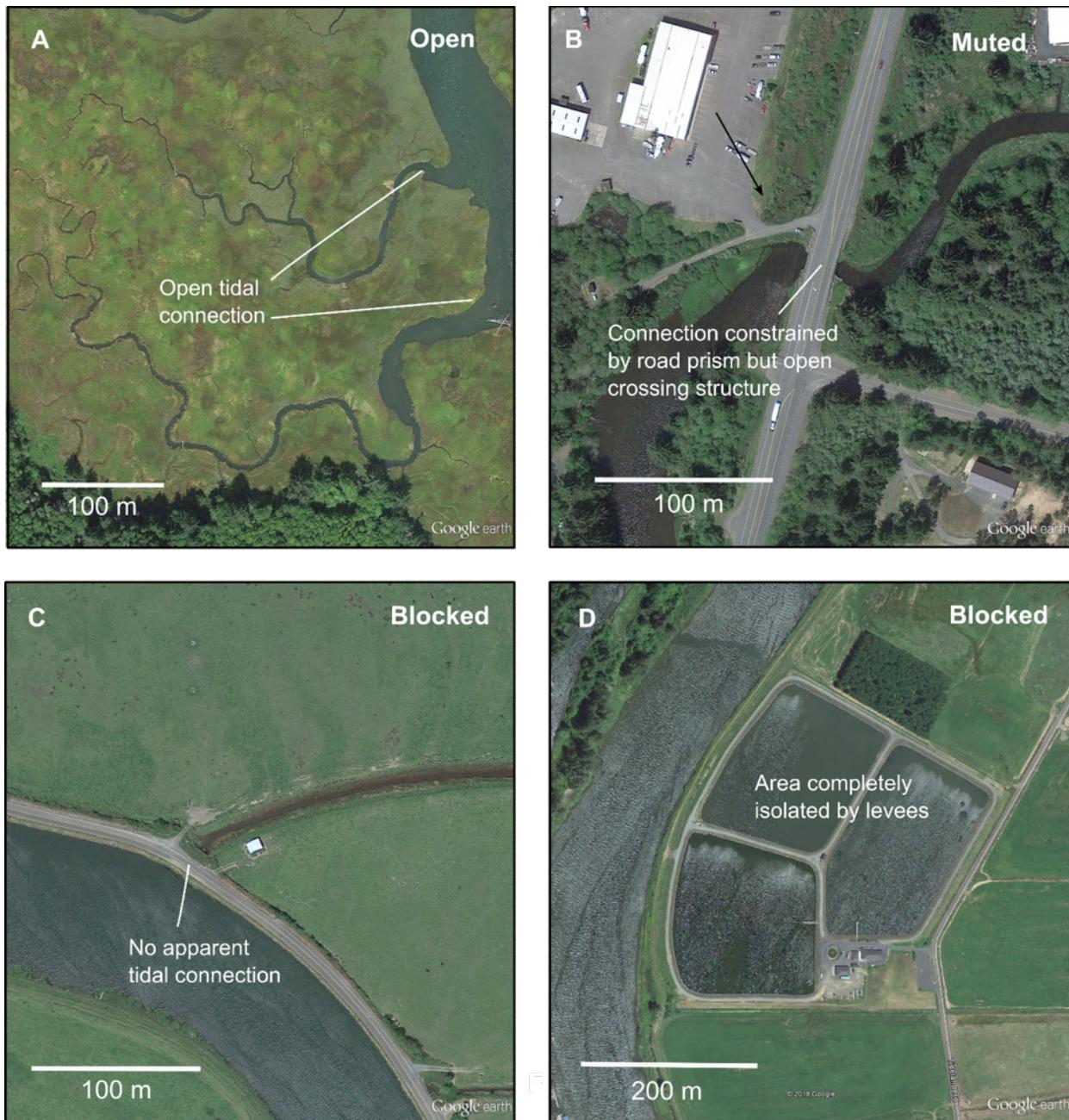


Figure 6. Examples of (A) open tidal connection, (B) muted tidal connection through a bridge or box culvert, (C) blocked tidal connection at a road prism, and (D) completely isolated delta area.

The polygon layer attribute table includes fields such as:

- F\_Type: Delta feature type; includes Delta Boundary and Low Density Marsh extent
- Delta: A three digit delta code
- MPG: Major population group identifier
- Area: Area of each feature (m<sup>2</sup>)
- Tidal Connectivity: Connected, Disconnected, Fill, Island, Muted, or Restored

## Nearshore Boundaries

We delineate the nearshore analysis area in Puget Sound with a 200-m buffer landward of the shoreline or high water mark. On the seaward side, we include all habitat features and built structures near the shore. The landward buffer delineates the analysis area for land cover change, as well as the inland distance within which we measure overwater structures (e.g., a highway bridge over a tidal channel). In most cases overwater structures intersect the shoreline (e.g., dock and piers), but in some cases structures can be several hundred meters from the shore (e.g., log booms, floating net pens, bridges connecting landforms). Note that we did not evaluate nearshore habitats on the Oregon Coast because there is minimal development or habitat change outside of the river deltas and bays.

In the Puget Sound study region, we needed a nearshore habitat typology that could capture the diversity of shoretypes that are found along the coastline. We decided to use the model developed by McBride et al. 2009 for the Salmon and Steelhead Habitat Inventory and Assessment Program or SSHIAP. This layer sufficiently captured shoreline habitat features called pocket estuaries and beaches that are documented to be used more frequently by juvenile salmonids than adjacent nearshore areas in parts of Puget Sound (Beamer and Fresh 2012, Beamer et al. 2006). For this project, we needed the shoretype segments to be at a scale appropriate for evaluating and comparing adjacent land cover status, and therefore we were required to group and segment the existing SSHIAP shoreline layer. The following protocol describes how we processed the SSHIAP shoreline layer.

Table 1. Crosswalk between McBride Model and classification of shoreline in Puget Sound for the Salmon Habitat Status and Trends monitoring project.

SHSTM Classification	McBride Model
Open rocky shoreline	Plunging rocky shoreline Rocky shoreline Veneered rock platform Rocky beach
Open beach shoreline	Depositional beach Sediment source beach Barrier beach Plunging sediment bluff Beach seep
Embayment beach type	Pocket beach
Embayment lagoon type	Delta Delta lagoon Tidal delta lagoon Drowned channel lagoon Longshore lagoon Tidal channel lagoon Tidal delta Drowned channel Tidal channel marsh Pocket beach lagoon Pocket closed lagoon and marsh Pocket beach estuary
Modified	Modified

The protocols for processing the shoreline polyline layer are:

1. In GIS, convert all layers to the same projection as land cover raster file (C-CAP).
2. Add the appropriate layers to the data frame within ArcMap.
3. To combine shoreline segments with the same shoretype: *Dissolve* by the GeoUnit attribute
  - Uncheck the “Create multipart features” box
  - a. Add two new fields to the dissolved shoreline layer
    - Name one SegLgth\_M, *Type: Long Integer*
    - Right click on the column title to *Calculate Geometry* and select your unit
    - Name the other GeoClass, *Type: text*
  - b. Select by attributes the GeoUnit types that are to be grouped according to SHSTM classifications (Table 1). For example the Pocket beach GeoUnit is in the embayment beach type GeoClass
  - c. Right click on the GeoClass column title and select *Field Calculator*
    - Enter the GeoClass category for selection. Enclose in “”
  - d. Repeat steps b and c until all GeoUnits have been assigned a GeoClass
4. In order to segment shoreline into more standardized lengths: Use ET GeoWizard split polyline tool using the dissolved shoreline layer
  - a. Select the equal length option
  - b. Select 200m for length
5. To create a buffer of 200m, start by selecting the *Euclidean Allocation* tool within the *Spatial Analysis Toolbox* (The Euclidean Allocation tool will create a raster layer on each side of the shoreline for each record or shoreline segment).
  - a. Use the 200m segmented shoreline polyline layer as the input
  - b. Use the unique Id number for segments as the Source field
  - c. Enter 200m for Maximum Distance
  - d. Enter 10m for the Output Cell Size (or same as land cover data)
6. To create a layer that represents only the inland area of the raster buffer (since creating a buffer raster layer does not allow you to distinguish the correct inshore side of the shoreline).
  - a. Make a copy of the shoreline layer
  - b. Turn on the editor tool bar for the temporary shoreline polyline layer and draw a line on the inshore side to capture the inland area and any other areas that are not enclosed
  - c. Convert the temp shoreline layer to a polygon using the *Feature to Polygon* within the *Data Management Toolbox*
  - d. *Extract by Mask* using the Euclidean Allocation raster as the *Input raster* and the new 200m inshore polygon layer as the *Input feature mask*
7. Reclassifying the land cover raster data to capture shoreline segments <30m
  - a. Select the *Reclassify* tool within the *3D Analyst Toolbox*
  - b. Input the land cover raster layer
  - c. Select the unique segment Id as the Reclass field
  - d. Change the “NoData” value to “0” in the “New values” column
  - e. Set the *Output Cell Size* to same as the raster buffer layer created from the Euclidean Allocation

- f. Select “Nearest” for the *Resampling Technique*
- g. Within *Environments* set the process extent equal to the original Euclidean Allocation layer and the XY Resolution to 10m
8. Assign dominant land cover type for each segment
  - a. Open the *Zonal Statistics as Table* tool
  - b. The *Input raster* will be the raster buffer created from the Euclidean Allocations in step 6
  - c. Select the unique segment Id, in this case the “VALUE” attribute for *Zone field*
  - d. The input value raster will be your land cover raster layer (use the extracted forest, agriculture, and developed CCAP layers one at a time)
  - e. Select “Majority” for the statistics type to help you identify land cover type when calculating in later steps
9. The output will be three tables that have a count of the number of cells within a particular land cover class (forest, agriculture, and developed) and the Id or “Value” column which is associated with the shoreline segment Id
10. Join the three zonal statistics tables to the original segment file and calculate the percentage for each land cover type using the cell count for each LCC and the total of the three in each segment buffer (as opposed to the total cell count for the segment buffer since not all land classes, mainly water, are included).
11. Assign each segment a dominant land cover type (LCC) if one type is 50% or more. If neither forest, agriculture or developed is at least 50%, assign the segment a “mixed” land cover category
  - a. Create a CSV file of the table with percentages and assign the dominant LCC to each segment in R studio
12. Add this column to the shoreline segment layer’s attribute table
  - a. Open the CSV file with dominant LCC in arc map
  - b. *Join* this table to the shoreline segment layer by “VALUE”
    - Right click on the shoreline segment layer in the table of contents window
    - Select *Joins and Relates* → *Join*
    - The “VALUE” field in the segment layer and LCC csv file should be the field that the join is based on

#### Assign Segments to Marine Basins:

1. Spatially join the Marine Basins layer with the shoreline segment layer so that each shoreline segment has a dominant LCC as well as a Marine Basin name
  - a. Create Marine Basins layer using steelhead and Chinook MPG boundaries as rough guide
    - Edit → Auto Fill Polygon tool – to capture shoreline not encompassed by original MPG boundary layers
    - Assign appropriate Marine Basin (Table 2) name to new polygon features
    - Dissolve by Marine Basin name
  - b. Use the *Spatial join* tool within the *Analysis* toolbox
    - Select the shoreline segment layer for “Target Features.” For “Join features” select the edited Marine Basins layer. Select “JOIN ONE TO ONE” for the “Join Operation” and “INTERSECT” for match options

Table 2. Crosswalk between Marine Basin names and Steelhead MPG and Chinook ESU names.

<b>Marine Basin</b>	<b>Steelhead MPG</b>	<b>Chinook ESU</b>
<b>South Central Puget Sound</b>	South-Central Cascades	Central/South Basin
<b>Hood Canal</b>	Olympic	Hood Canal
<b>Whidbey Basin</b>	Whidbey Basin	Northern Cascades
<b>North Puget Sound</b>	Strait of Georgia	Northern Cascades
<b>Strait of Juan de Fuca</b>	Olympic	Strait of Juan de Fuca

The Nearshore shoreline layer attribute table includes a unique record number, associated segment length, delta presence (if the segment is within our delta boundaries), and any stratification attributes that are assigned to each segment such as geounit, geoclass, land cover, and Marine Basin. The attribute table for Puget Sound nearshore includes:

- Seg\_ID: Unique shoreline segment identifier
- SegLgth\_M: Length in meters of segment
- GeoUnit: Shoretype classification from SSHIAP
- GeoClass: Shoretype classification grouped for SHST monitoring project
- DeltaPres: 0 = segment is not within delta boundary, 1 = segment is within delta boundary
- D\_LC: percent developed land cover within 200 m inland
- F\_LC: percent forest land cover within 200 m inland
- Ag\_LC: percent agriculture land cover within 200 m inland
- LCC: Dominant land cover class, developed using C-CAP 2010 data, which we aggregated into forest/wetland (F), agriculture (Ag), and developed (D) classes
- MarinBasin: Marine Basins of Puget Sound, which include North Puget Sound, Whidbey Basin, Strait of Juan de Fuca, Hood Canal, and South Central Puget Sound

## Monitoring Protocols

In developing monitoring metrics in Puget Sound, we evaluated 115 potential metrics for monitoring status and trends of large river, floodplain, delta, and nearshore habitats (Beechie et al. 2017). After a systematic evaluation based on five scoring criteria, 42 metrics were selected for use in the monitoring program. After field trials in 2014 and 2015, we dropped all field metrics because they were not cost-effective to measure, and we dropped the large river aerial photograph metric of sinuosity because it was not sensitive to land use (Beechie et al. 2017). For length of armored shoreline we are deferring to the Puget Sound Partnership, which has a group tasked with updating GIS data for shoreline armor. Since 2015, we have developed protocols for 22 of the remaining large-river, floodplain, delta, and nearshore metrics, which we detail in the following sections (Table 3). We used a subset of these same metrics on the Oregon Coast. The descriptions of large river and floodplain, delta, and near shore habitat metrics are provided in Tables 4, 5, and 6, respectively.

Table 3. Updated list of habitat metrics for monitoring salmon habitat status and trends in Puget Sound and on the Oregon Coast. We have developed monitoring protocols for each of the metrics in bold. Metrics in light gray type were selected for monitoring in our metric selection process (Beechie et al. 2017), but we have not yet developed protocols for them.

Data Resolution	Monitoring Environment			
	Large river	Floodplain	Delta	Nearshore
Satellite	—	<ul style="list-style-type: none"> <li>• % forest land cover</li> <li>• % agricult. land cover</li> <li>• % developed land cover</li> </ul>	<ul style="list-style-type: none"> <li>• % forest land cover</li> <li>• % agricult. land cover</li> <li>• % developed land cover</li> </ul>	<ul style="list-style-type: none"> <li>• % forest land cover in 200-m buffer</li> <li>• % agricult. land cover in 200-m buffer</li> <li>• % developed land cover in 200-m buffer</li> </ul>
Aerial photography/ lidar	<ul style="list-style-type: none"> <li>• <b>Riparian buffer width</b></li> <li>• <b>Wood jam area</b></li> <li>• <b>Backwater area</b></li> </ul>	<ul style="list-style-type: none"> <li>• <b>Braid: Main channel length ratio (<math>L_{bc}/L_{main}</math>)</b></li> <li>• <b>Side-channel: Main channel length ratio (<math>L_{sc}/L_{main}</math>)</b></li> <li>• <b>Braid node density</b></li> <li>• <b>Side-channel node density</b></li> <li>• % of floodplain disconnected</li> <li>• Length of side channel</li> <li>• Area of connected floodplain</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Proportion of delta disconnected</b></li> <li>• <b>Tidal channel area and edge habitat length</b></li> <li>• <b>Tidal channel length</b></li> <li>• <b>Tidal channel node density</b></li> </ul>	<ul style="list-style-type: none"> <li>• <b>Area of overwater structures</b></li> <li>• Length of forested shoreline</li> <li>• Area of eelgrass and kelp</li> <li>• Embayment area (total, wetted, veg)</li> <li>• Connectivity of embayment to nearshore (width of opening)</li> </ul>

Table 4. Descriptions of selected habitat metrics for large river and floodplain habitats.

<b>Metric</b>	<b>Description</b>
Percent forest/wetland land cover in floodplain	Percentage of the total floodplain land area in forest or wetland cover
Percent agricultural land cover in floodplain	Percentage of the total floodplain land area in agricultural cover
Percent developed land cover in floodplain	Percentage of the total floodplain land area in low-, moderate-, or high-density developed cover
Braid:Main channel length ratio	Total braid length in the reach divided by main channel length (Friend and Sinha 1993; Beechie et al. 2006)
Side-channel:Main channel length ratio	Total side-channel length in the reach divided by main channel length (Friend and Sinha 1993; Beechie et al. 2006)
Braid node density	Number of braid junctions per km of main channel (Luck et al. 2010)
Side-channel node density	Number of side-channel junctions per km of main channel (Luck et al. 2010)
Backwater (alcove) area	Area of backwaters within the active channel divided by main channel length
Wood jam area	Area of wood jams within the active channel divided by main channel length
Riparian buffer width	Width of riparian buffer along 68-meter transects originating from stream bankfull edge

Table 5. Descriptions of selected habitat metrics for delta habitat.

<b>Metric</b>	<b>Description</b>
Percent forest/wetland land cover in delta	Percentage of the total delta land area in forest or wetland cover
Percent agricultural land cover in delta	Percentage of the total delta land area in agricultural cover
Percent developed land cover in delta	Percentage of the total delta land area in low-, moderate-, or high-density developed cover
Proportion of delta disconnected	Area of delta with blocked or muted tidal connection, or area of fill
Tidal channel area and edge habitat length	Area and the length of perimeter of tidal channels within the delta
Tidal channel length	Length of tidal channels within the delta
Tidal channel node density	Number of tidal channel junctions per km of main channel

Table 6. Descriptions of selected habitat metrics for nearshore habitat.

<b>Metric</b>	<b>Description</b>
Percent forest/wetland land cover in 200-m buffer	Percentage of the shoreline 200-meter buffer area in forest or wetland cover
Percent agricultural land cover in 200-m buffer	Percentage of the shoreline 200-meter buffer area in agricultural cover
Percent developed land cover in 200-m buffer	Percentage of the shoreline 200-meter buffer area in low-, moderate-, or high-density developed cover
Area of overwater structures	Area of overwater structures in the nearshore, located up to 200 meters inland of the shoreline or visible high-water mark

## Large River and Floodplain

We based our monitoring protocols for large river and floodplain areas on several sources, including WFPB (2011), Beechie et al. (2006a), and Fullerton et al. (2006). These sources described general methods of measuring channel and riparian characteristics, but monitoring protocols require greater specificity to create a repeatable methodology for monitoring trends over time. We developed these protocols over several trials, using inter-observer comparisons to help identify and correct errors or omissions in the protocols (i.e., to identify where increased specificity in the protocols could reduce inter-observer variation).

### Percent Forest, Agricultural, or Developed Land Cover in Floodplains

Two layers are required for this analysis: 1) C-CAP land cover data, and 2) a floodplain polygon layer. The attribute necessary within the land cover dataset is the land cover class. The floodplain polygon layer will require a Reach ID (unique reach identifier) and MPG name (major population group identifier) for each reach, as well as the area of the reach.

The protocols for calculating percent of land cover by MPG are:

1. Convert all layers to the same projection as the land cover raster layer.
2. Add the appropriate layers to the data frame within ArcMap.
3. To calculate total area of floodplain within each MPG, use the *Summarize* function on MPG field, summarize area and add resulting table to the data frame.
4. Join resulting table to the floodplain polygon layer to assign area for each MPG. Create a new MPG area field and update it to the values from joined table using *Field Calculator*
5. Using *Reclassify* tool, reclass the land cover classes of interest from the C-CAP data as separate raster layers. See Table 7 for the groupings of C-CAP land cover classes.
6. Run *Tabulate Area* tool for each reclassified land cover raster layer using the floodplain polygon layer as input feature zone data and a MPG as the zone field. The input raster will be the land cover raster layer and class field will be value associated with land cover.
7. When you have run *Tabulate Area* for all reclassified land cover raster layers, join the resulting tables to the original floodplain polygon layer (ensuring you keep all records), and create new fields: percent forest, percent agriculture, and percent developed.
8. Within the created field(s), using *Field Calculator* calculate:

$$\% \text{ forest by MPG} = \frac{\text{sum of forest area in MPG}}{\text{total area of floodplains in MPG}}$$

$$\% \text{ agriculture area by MPG} = \frac{\text{sum of agriculture area in MPG}}{\text{total area of floodplains in MPG}}$$

$$\% \text{ developed area by MPG} = \frac{\text{sum of developed area in MPG}}{\text{total area of floodplains in MPG}}$$

Table 7. Groupings of original C-CAP land cover classes into five main classes for stratification of sample sites in Puget Sound large rivers, floodplains, deltas, and the nearshore.

<b>Land-cover class<sup>a</sup></b>	<b>Original C-CAP land-cover classes</b>	
Forest/Wetland	Grassland Evergreen forest Scrub/shrub Palustrine scrub/shrub wetland Delta forest wetland Estuarine emergent wetland	Deciduous forest Mixed forest Palustrine forested wetland Palustrine emergent wetland Estuarine scrub/shrub wetland Unconsolidated shore
Agriculture	Cultivated land	Pasture/hay
Developed	High-intensity developed Low-intensity developed	Medium-intensity developed Developed open space
Water	Open water Delta aquatic bed	Palustrine aquatic bed
Other	Unclassified Tundra	Bare land Snow/ice

<sup>a</sup> Assigned by monitoring program.

The protocols for calculating percent land cover by floodplain sample reach are:

1. Convert all layers to the same projection as the land cover raster file.
2. Add the appropriate layers to the data frame within ArcMap.
3. Using the *Reclassify* tool, reclass the land cover classes of interest from the C-CAP data as separate raster layers. See Table 7 for the groupings of C-CAP land cover classes.
4. Run *Tabulate Area* for each land-class raster layer using the floodplain polygon layer as input feature zone data and a Reach ID as zone field. The input value raster will be the land cover raster layer and class field will be value associated with land cover.
5. When *Tabulate Area* has been calculated for all land cover types, join the resulting tables to the original polygon layer (so you are sure to keep all records), and create new fields for percent forest, percent agriculture, and percent developed.
6. Within the created fields, using *Field Calculator* calculate:

$$\% \text{ forest area in sample reach} = \frac{\text{forest area in sample reach}}{\text{area of floodplain sample reach}}$$

$$\% \text{ agricultural area in sample reach} = \frac{\text{agricultural area in sample reach}}{\text{area of floodplain sample reach}}$$

$$\% \text{ developed area in sample reach} = \frac{\text{developed area in sample reach}}{\text{area of floodplain sample reach}}$$

## Channel and Habitat Feature Measurements

The GIS layers needed to begin the aerial photography measurements are:

1. The aerial imagery layer (preferably 0.3-m resolution or better),
2. The floodplain polygon with the unique Reach ID identifier,
3. A new polyline layer for each of the channel type measurements,
4. A new point layer for each of the channel type node measurements, and
5. A new polygon layer to contain wood jam area and backwater area measurements.

For each of the measurement layers, the attribute table should include:

- Type: The category of a feature being measured (see list below)
- Reach ID: Associated with the site location
- Year: Extracted from the aerial imagery layer
- Date: Extracted from the aerial imagery layer
- Observer: The name of the observer performing the measurements
- Comment: A field where observers can enter comments
- Length or Area: The calculated line length for polyline features or calculated polygon area for polygon features

The Large River and Floodplain measurements include:

- Main channel: Contains the majority of the river discharge.
- Braid: Secondary flow path that contains less than half of the discharge, separated from the main channel by an unvegetated gravel bar (Figure 7).
- Side channel: Secondary flow path that contains less than half of the discharge, separated from the main channel by a vegetated island (Figure 8).
- Wood Jam: Wood jam comprising stacked pieces of wood in water, on the bank, or on an island within the active channel area (Figure 9).
- Backwater: an area of still water within a main channel, side channel, or braid (Figure 10).

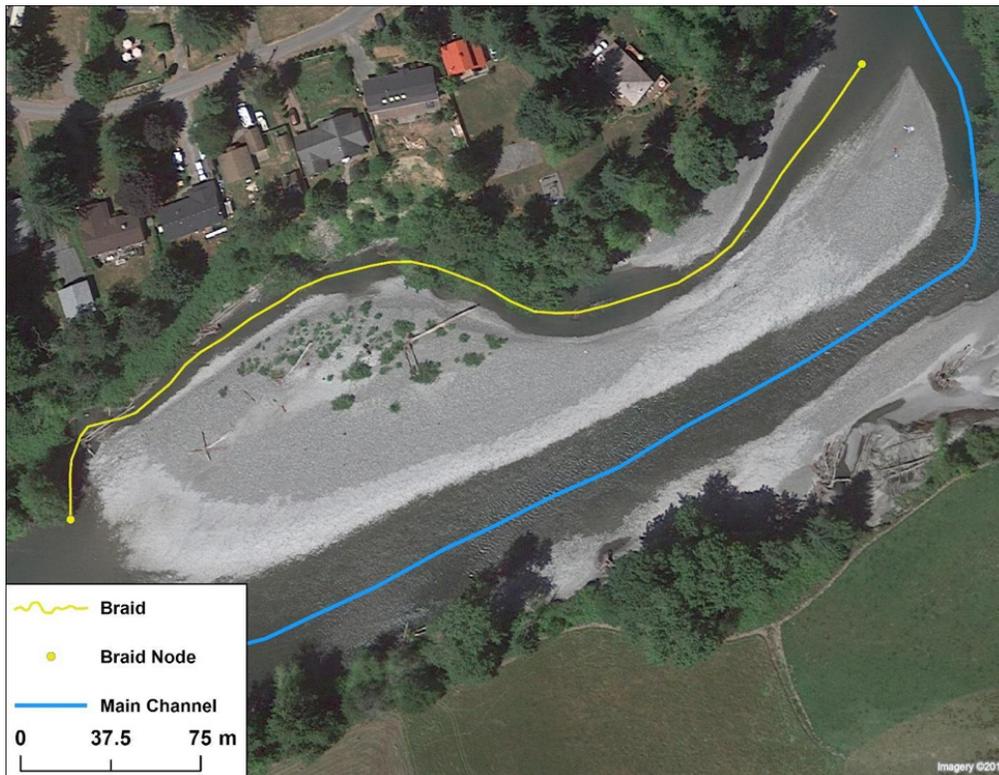


Figure 7. Example of digitized braid and braid node features using the large river aerial photography protocol, Stillaguamish River, Washington.

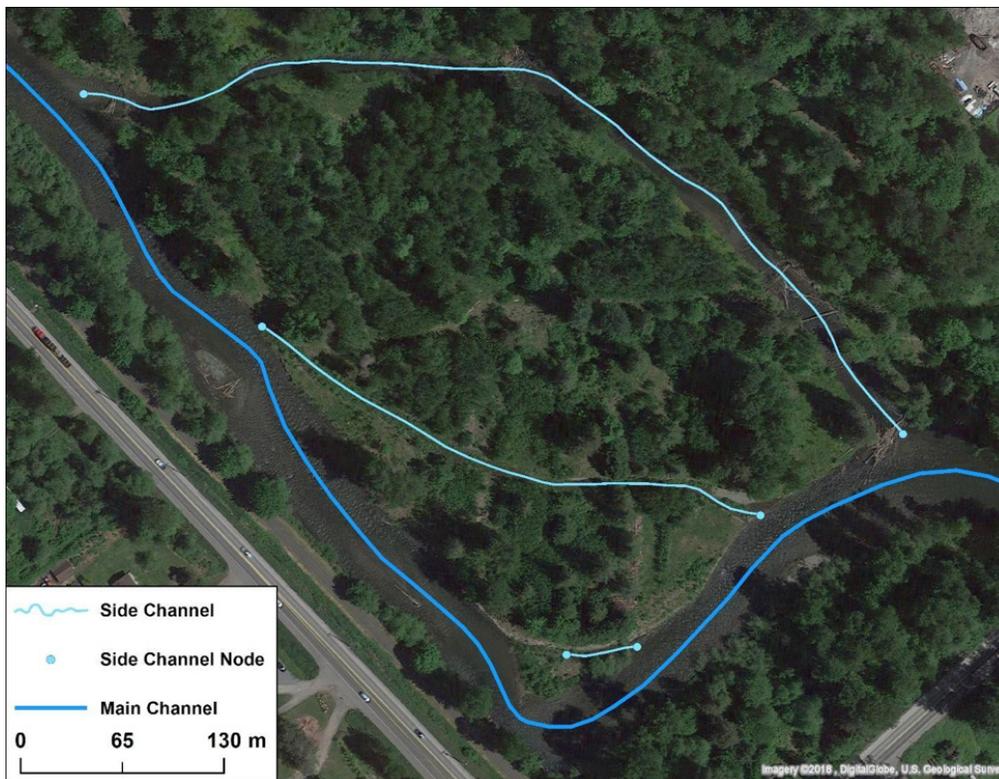


Figure 8. Example of digitized side channel and side channel node features using the large river aerial photography protocol, Cedar River, Washington.

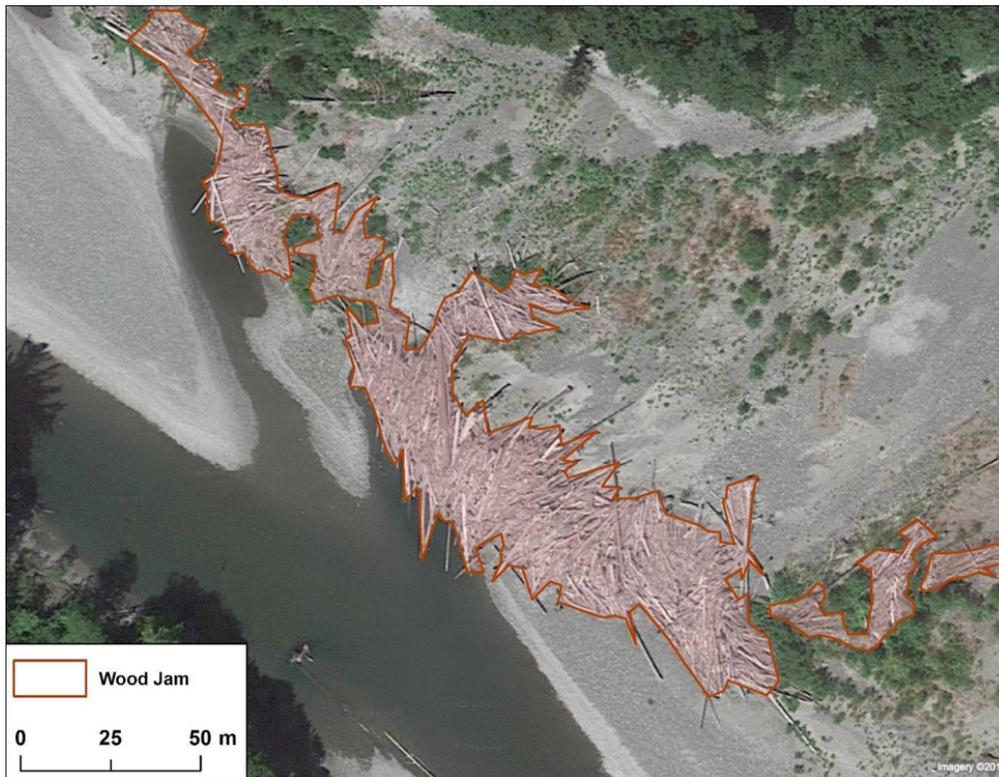


Figure 9. Example of digitized wood jam area using the protocol. Small jams and single wood pieces were not digitized, as they did not meet the requirement of minimum area  $>20\text{ m}^2$ , Stillaguamish River, Washington.



Figure 10. Example of digitized backwater area using the protocol, Stillaguamish River, Washington.

The protocols for aerial photography channel and habitat measurements are:

1. Add the appropriate layers to the data frame within ArcMap.
2. Digitize the main channel line for the reach by tracing a line along the thalweg.
3. Digitize each braid and side channel using the following criteria:
  - a. Only digitize a channel if more than half of its wetted length is clearly visible
  - b. Braid and side channels can be connected within the floodplain, but should not extend past the edge habitat line and should not be connected to the main channel line (i.e., they should end at the edge of the main channel). Do not digitize braids or side channels shorter than 10 m in length.
  - c. Where a floodplain has been disconnected and water does not flow regularly, side channels or braids should not be digitized.
  - d. If a channel is separated from the large river by a vegetated island, designate it as a side channel; if it is separated by an unvegetated island (i.e., gravel bar), designate it as a braid.
  - e. If it is unclear whether a feature can be classified as an island with a channel, other imagery during different flow conditions can be referred to (if available).
4. Digitize braid and side channel nodes by placing a point at the ends of each digitized channel polyline.
5. Digitize each wood jam that is visible within the main channel, side channels, braid, and/or functional floodplain. Wood jams should only be measured when:
  - a. The wood jam includes key and racked wood pieces.
  - b. The wood jam is visible and its contiguous area is at least 20 m<sup>2</sup>.
  - c. Only key and adjoining and visible pieces of wood are included in the wood jam area measurement.
6. Digitize each backwater that is visible within the main channel, side channel, or braid.
  - a. Only backwaters adjoining the main channel or braids should be measured, including backwaters that are at the downstream end of a side channel, braid, or tributary that connects to the main channel.
  - b. Only backwaters >20 m<sup>2</sup> should be measured.
  - c. Isolated pools or ponds within a floodplain should not be considered a backwater.

## Braid:Main Channel Length Ratio

The GIS layers needed to calculate braid:main channel length ratio are: 1) the floodplain polygon with the unique Reach ID and MPG identifiers, 2) the main channel polyline layer, and 3) the braid channel polyline layer .

The protocols for calculating braid:main channel length ratio are:

1. Add the appropriate layers to the data frame within ArcMap.
2. Create a length field within main channel and braid polyline layers.
3. Using *Calculate Geometry*, calculate length for each of layers' polylines in meters.
4. Using *Summarize* function on Reach ID field, summarize length field for main channel and braid layers and add resulting tables to the data frame.
5. Join resulting main channel and braid channel tables to floodplain layer by Reach ID.

6. To calculate braid:main channel ratio for each reach, create a new field and use *Field Calculator* to divide braid length by main channel length.
7. To calculate braid:main channel ratio for MPG, first calculate total length of braid and main channel within each MPG. Using *Summarize* function on the MPG field, summarize the length field for main channel and braid layers and add resulting tables to the data frame.
8. Join resulting main channel and braid channel tables by MPG.
9. To calculate braid:main channel ratio for each MPG, create a new field and using *Field Calculator* divide braid length by main channel length.

## Braid Node Density

The GIS layers needed to calculate braid node density are: 1) the floodplain polygon with unique Reach ID identifier and MPG identifier, 2) the main channel polyline layer, and 3) the braid node point layer.

The protocols for calculating braid node density are:

1. Add the appropriate layers to the data frame within ArcMap.
2. Create a length field within main channel polyline layer and, using *Calculate Geometry*, calculate main channel length in meters.
3. Create count field within braid node point layer and, using *Field Calculator*, populate each point with value of 1.
4. Using *Summarize* function on Reach ID field, summarize length field for main channel layer and count field for braid node layer and add resulting tables to the data frame.
5. Join resulting main channel and braid node tables to floodplain layer by Reach ID.
6. To calculate braid node density for each reach, create a new field and using *Field Calculator* divide number of braid nodes by main channel length.
7. To calculate braid node density for MPG, first calculate total length main channel and total count of braid nodes within each MPG. Using *Summarize* function on the MPG field, summarize length field for main channel layer and count field for braid node layer and add the resulting tables to the data frame.
8. Join resulting main channel and braid node tables by MPG.
9. To calculate braid node density for each MPG, create a new field and using *Field Calculator* divide number of braid nodes by main channel length.

## Side-channel:Main Channel Length Ratio

The GIS layers needed to calculate side-channel:main channel length ratio are: 1) the floodplain polygon with unique Reach ID and MPG identifier, 2) the main channel polyline layer, and 3) the side-channel channel polyline layer.

The protocols for calculating side-channel:main channel length ratio are:

1. Add the appropriate layers to the data frame within ArcMap.
2. Create a length field within main channel and side-channel polyline layers. Using *Calculate Geometry*, calculate length for each of layers' polylines in meters.

3. Using *Summarize* function on Reach ID field, summarize length field for main channel and side-channel layers and add resulting tables to the data frame.
4. Join resulting main channel and side-channel tables to floodplain layer by Reach ID.
5. To calculate side-channel:main channel ratio for each reach, create a new field and using *Field Calculator* divide side-channel length by main channel length.
6. To calculate side-channel:main channel ratio for MPG, first calculate total length of side-channel and main channel within each MPG. Using *Summarize* function on the MPG field, summarize the length field for main channel and side-channel layers and add resulting tables to the data frame.
7. Join resulting main channel and side-channel tables by MPG.
8. To calculate side-channel:main channel ratio for each MPG, create a new field and using *Field Calculator* divide side-channel length by main channel length.

## Side-channel Node Density

The GIS layers needed to calculate side-channel node density are: 1) the floodplain polygon with unique Reach ID identifier and MPG identifier, 2) the main channel polyline layer, and 3) the side-channel node point layer.

The protocols for calculating side-channel node density are:

1. Add the appropriate layers to the data frame within ArcMap.
2. Create a Length field within main channel polyline layer and, using *Calculate Geometry*, calculate main channel length in meters.
3. Create Count field within side-channel node point layer and, using *Field Calculator*, populate each point with value of 1.
4. Using *Summarize* function on Reach ID field, summarize length field of main channel layer and count field of side-channel node layer and add resulting tables to the data frame.
5. Join resulting main channel and side-channel node tables to floodplain layer by Reach ID.
6. To calculate side-channel node density for each reach, create a new field and using *Field Calculator* divide number of side-channel nodes by main channel length.
7. To calculate side-channel node density for MPG, first calculate total length main channel and total count of side-channel nodes within each MPG. Using *Summarize* function on the MPG field, summarize the length field for main channel layer and count field for side-channel node layer and add resulting tables to the data frame.
8. Join resulting main channel and side-channel node tables by MPG.
9. To calculate side-channel node density for each MPG, create a new field and using *Field Calculator* divide number of side-channel nodes by main channel length.

## Wood Jam Area

The GIS layers needed to calculate wood jam area are: 1) the floodplain polygon with unique Reach ID identifier and MPG identifier, 2) main channel polyline layer, and 3) the wood jam polygon layer.

The protocols for calculating wood jam area are:

1. Add the appropriate layers to the data frame within ArcMap
2. Create a length field within main channel polyline layer and, using *Calculate Geometry*, calculate main channel length in kilometers.
3. Create area field within wood jam polygon layer and, using *Calculate Geometry*, calculate wood jam area in square meters.
4. Using *Summarize* function on Reach ID field, summarize length field of main channel layer and area field of wood jam polygon layer and add resulting tables to the data frame.
5. Join resulting main channel and wood jam tables to floodplain layer by Reach ID.
6. To calculate wood jam area per reach length, create a new field and using *Field Calculator* divide wood jam area by main channel length.
7. To calculate wood jam area for MPG, first calculate total length main channel and total wood jam area within each MPG. Using *Summarize* function on MPG field, summarize length field for main channel layer and area for wood jam layer and add resulting tables to the data frame.
8. Join resulting main channel and wood jam tables by MPG.
9. To calculate wood jam area for each MPG, create a new field and using *Field Calculator* divide wood jam area by main channel length.

## Backwater Area

The GIS layers needed to calculate backwater (alcove) area are: 1) the floodplain polygon with unique Reach ID identifier and MPG identifier, 2) main channel polyline layer, and 3) the backwater polygon layer.

The protocols for calculating backwater area are:

1. Add the appropriate layers to the data frame within ArcMap
2. Create a length field within main channel polyline layer and, using *Calculate Geometry*, calculate main channel length in kilometers.
3. Create area field within backwater polygon layer and, using *Calculate Geometry*, calculate backwater area in square meters.
4. Using *Summarize* function on Reach ID field, summarize length field of main channel layer and area field of backwater polygon layer and add resulting tables to the data frame.
5. Join resulting main channel and wood jam tables to floodplain layer by Reach ID.
6. To calculate backwater area per reach length, create a new field and using *Field Calculator* divide backwater area by main channel length.

7. To calculate backwater area for MPG, first calculate total length main channel and total backwater area within each MPG. Using the *Summarize* function on the MPG field, summarize length field for main channel layer and area for backwater layer and add resulting tables to the data frame.
8. Join resulting main channel and backwater tables by MPG.
9. To calculate backwater area for each MPG, create a new field and using *Field Calculator* divide backwater area by main channel length.

## Riparian Buffer Width

The GIS layers needed to begin the riparian buffer measurements are: 1) the aerial imagery layer, 2) the floodplain polygon with unique Reach ID identifier and MPG identifier, 3) a new polyline layer for bankfull line measurements, 4) a new point layer to contain transect origins along the bankfull line, and 5) a new polyline layer to contain buffer transect measurements.

For bankfull line layer, the attribute table includes:

- Type: Bankfull line
- Bank: Left or Right (downstream direction)
- Reach ID: Sample reach identifier
- MPG: Major population group identifier
- Year: Extracted from the aerial imagery layer
- Date: Extracted from the aerial imagery layer
- Observer: The name of the observer performing the measurements
- Comment: A field where observers can enter comments
- Length: The calculated line length for polyline features

The protocols for riparian buffer measurements are:

1. Digitize bankfull lines along the outer bankfull edge of the outermost channel (main channel, braid, or side channel at the furthest edge of floodplain). In other words, the bankfull edge line will be along the outside bankfull edge of active channel area encompassing all visible channels (Figure 11).
2. Digitize the area of each island along established vegetation edge.
3. Along each of the bankfull lines within a reach, create ten equidistant points for a total of 20 points.
4. Spatially join created points with bankfull lines to transfer bankfull line attributes to each point.
5. At each point, digitize a buffer transect perpendicular to the bankfull edge, if forested land cover is present at the point.
  - a. The maximum length of a transect is 68 m (225 feet, the height of mature conifer trees >200 years old, McArdle et al. 1961). If forest cover ends before 68 m is reached, the transect ends at that point and its length is recorded (Figure 11).
6. Spatially join riparian transects to the points layer to transfer attributes from origin points layer to riparian buffer transect layer.
7. Using *Summarize* function on Reach ID field, calculate average of length field of riparian transect layer and add resulting table to the data frame.

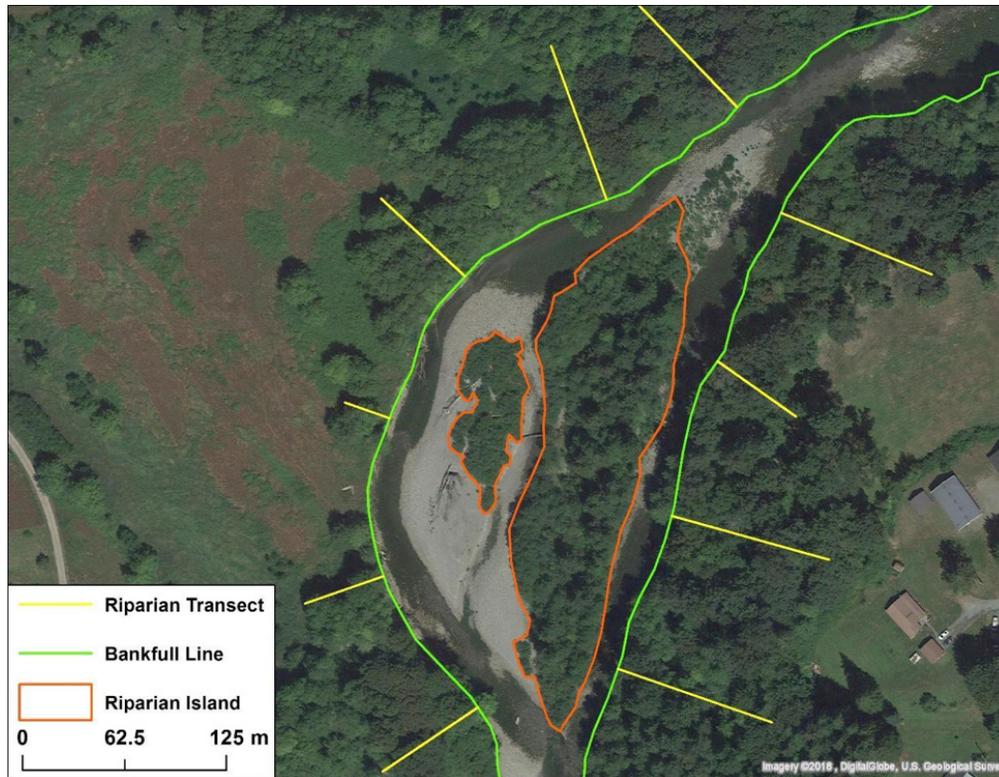


Figure 11. Examples of digitized bankfull edge lines, island boundaries, and riparian buffer widths using the riparian buffer width protocols.

8. Join resulting riparian transect tables to floodplain layer by Reach ID.
9. To calculate riparian buffer width for MPG, using the *Summarize* function on the MPG field, calculate average of riparian transect length field and add resulting tables to the data frame.

## Delta and Nearshore

We based our protocols for delta and nearshore areas on several sources, including Beamer et al. (2005) and Hood (2005, 2015). These sources described general methods of delineating functionally distinct tidally influenced channel and marsh features from aerial photography, but our protocols required much greater specificity in order to create a repeatable methodology for monitoring trends over time. We developed these protocols over several iterations of aerial photography trials.

### Percent Forest, Agricultural, or Developed Land Cover in Deltas

Two layers are required for this analysis: 1) C-CAP land cover data, and 2) a delta polygon layer. The attribute necessary within the land cover dataset is the land cover class. Within the delta polygon layer the necessary attributes are Delta ID (unique delta identifier), MPG name (major population group identifier) for each delta polygon, and area of the delta polygon.

The protocols for calculating percent of land cover by MPG are:

1. Convert all layers to the same projection as the land cover raster layer.
2. Add the appropriate layers to the data frame within ArcMap.
3. To calculate total area of delta within each MPG, using *Summarize* function on MPG field, summarize area and add resulting table to the data frame.
4. Join resulting table to the delta polygon layer to assign area for each MPG. Create a new MPG area field and update it to the values from joined table using *Field Calculator*.
5. Using *Reclassify* tool, reclassify the land cover classes of interest from the C-CAP data as separate raster layers. See Table 7 for the groupings of C-CAP land cover classes.
6. Run *Tabulate Area* tool for each reclassified land cover raster layer using the delta polygon layer as input feature zone data and a MPG as the zone field. The input value raster will be the land cover raster layer and class field will be value associated with land cover.
7. When you have completed running *Tabulate Area* for all reclassified land cover raster layers, join the resulting tables to the original delta polygon layer (so you are sure to keep all records), and create new fields for percent forest, percent agriculture, or percent developed.
8. Within the created field(s), using *Field Calculator* calculate:

$$\% \text{ forest by MPG} = \frac{\text{sum of forest area in MPG}}{\text{total area of deltas in MPG}}$$

$$\% \text{ agriculture area MPG} = \frac{\text{sum of agricultural area in MPG}}{\text{total area of deltas in MPG}}$$

$$\% \text{ developed area by MPG} = \frac{\text{sum of developed area in MPG}}{\text{total area of deltas in MPG}}$$

The protocols for calculating percent land cover by river delta are:

1. Convert all layers to the same projection as the land cover raster file.
2. Add the appropriate layers to the data frame within ArcMap.
3. Using *Reclassify* tool, reclassify the land cover classes of interest from the C-CAP data as separate raster layers. See Table 7 for the groupings of C-CAP land cover classes.
4. Run *Tabulate Area* for each land-class raster layer using the delta polygon layer as input feature zone data and unique delta identifier as zone field. The input value raster will be the land cover raster layer and class field will be value associated with land cover.
5. When *Tabulate Area* have been calculated for all land cover types, join the resulting tables to the original delta polygon layer (so you are sure to keep all records), and create new fields for percent forest, percent agriculture, and percent developed.
6. Within the created field(s), using *Field Calculator* calculate:

$$\% \text{ forest area in delta} = \frac{\text{forest area in delta}}{\text{area of delta}}$$

$$\% \text{ agricultural area in delta} = \frac{\text{agricultural area in delta}}{\text{area of delta}}$$

$$\% \text{ developed area in delta} = \frac{\text{developed area in delta}}{\text{area of delta}}$$

## Percent Forest, Agricultural, or Developed Land Cover in the Nearshore

Three layers are required for this analysis: 1) C-CAP land cover data, 2) Raster layer representing 200m inland buffer of the nearshore, and 3) Shoreline Segment layer. The attribute necessary within the land cover dataset is the land cover class. The raster buffer layer defines the 200m inland boundary and the necessary attribute within the shoreline segment layer is a unique shore-segment identifier (Seg\_ID).

The protocols for calculating percent of land cover by shoreline segment are:

1. Convert all layers to the same projection as the land cover raster layer.
2. Add the appropriate layers to the data frame within ArcMap.
3. If not done so already, use the reclassify tool to reclassify the land cover classes of interest from the C-CAP data as separate raster layers. See Table 7 for the groupings of C-CAP land cover classes.
4. Run Tabulate Area tool for each reclassified land cover raster layer using the 200m shoreline buffer layer as the input feature zone data and value as the zone field so that you can match records later. The input value raster will be the land cover raster layer and class field will be the value associated with the land cover.
5. When you have calculated Tabulate Area for all reclassified land cover raster layers, join the resulting tables to the original shoreline segment layer and create new fields for percent forest, percent agriculture, and percent developed.
6. Within the created fields, use the *Field Calculator* to calculate:

$$\% \text{ forest area in 200m buffer shoreline segment} = \frac{\text{forest area in shoreline segment}}{\text{total area in segment}}$$

$$\% \text{ agriculture area in 200m buffer shoreline segment} = \frac{\text{agriculture area in shoreline segment}}{\text{total area in segment}}$$

$$\% \text{ developed area in 200m buffer shoreline segment} = \frac{\text{developed area in shoreline segment}}{\text{total area in segment}}$$

## Delta Channel Measurements

Juvenile Chinook, coho and chum salmon utilize specific habitats in deltas where low water velocities and shallow water depths create favorable habitats for rearing. These favorable habitats occur primarily along the margins of distributary channels and blind tidal channels in delta estuaries (Beamer et al. 2005). However, the number of such habitats in coastal Washington and Oregon is not known given that tidal channel features have not been consistently mapped and quantified across the region. Mapping of tidal channel features throughout the region's major deltas is a first step toward quantifying the amount of tidal channel habitat while also providing a base layer from which numerous habitat quantity and quality metrics can be derived.

We digitized four tidal channel feature types as polygons within each delta unit: 1) distributaries, 2) tidal channels, 3) tidal channel complexes, and 4) tidal flats. Each type is functionally different with respect to fish habitat, and requires different protocols to ensure consistent delineation and measurement of channel features within deltas.

The Delta channel measurements include:

- Distributary: Channel with bankfull width greater than 2-3 meters wide that has a clear upstream connection to the main channel or other distributary, and is part or all of a continuous flow path from the river to the delta mouth (Figure 12).
  1. Primary Distributary: Channel that conveys the greatest amount of river flow downstream as determined by the size of channels at the bifurcations (Figure 12).
- Tidal Channel:
  1. Large tidal channel with a bankfull width of at least 2-3 meters without river connection at the upstream end (Figure 13).
  2. Small tidal channel: Tidal channels with bankfull width <2-3 meters without connection at the upstream end.
- Tidal Channel Complex: Dense tidal channel networks that occur at the terminal fringe of the delta, with numerous channels <2-3 m wide (Figure 14).
- Tidal Flat: Large unvegetated or low-density vegetation surfaces that occur interior of delta boundaries. Primarily associated with restoration projects where tidal connection has recently been restored and an established channel network with vegetated edges has not yet formed (Figure 15).

The GIS layers needed for the aerial photography measurements are: 1) the aerial imagery layer, 2) the delta polygon layer with unique delta identifier, 3) a new polygon layer for each of the delta channel type's measurements, and 4) a new polyline layer for small tidal channel measurements.

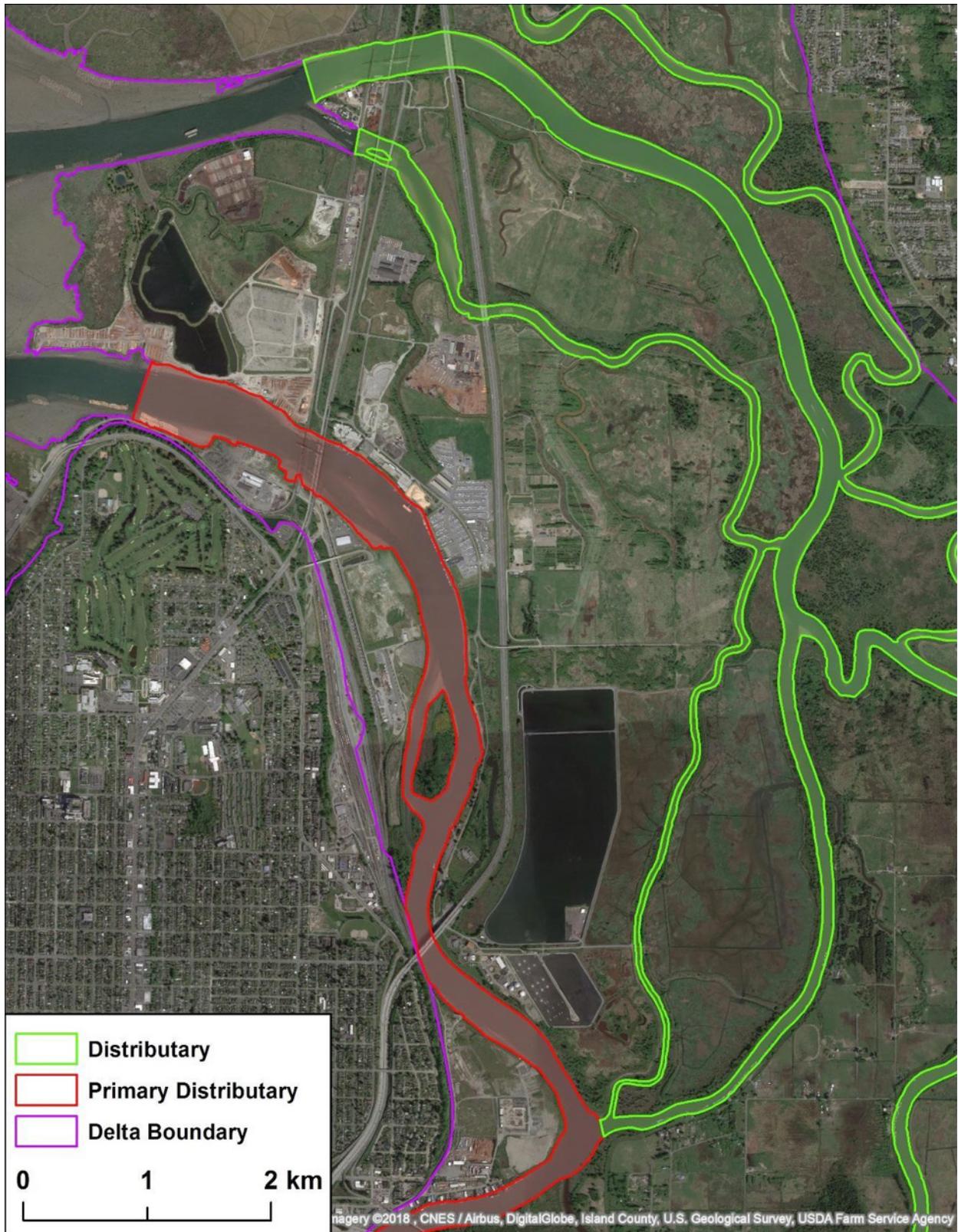


Figure 12. Example of digitized delta habitat features in the Snohomish River delta illustrating primary distributary and other distributaries.



Figure 13. Example of digitized delta habitat features in the Snohomish River delta illustrating tidal channels.



Figure 14. Example of digitized delta habitat features in the Snohomish River delta illustrating tidal channel complex.



Figure 15. Example of digitized delta habitat features in the Snohomish River delta illustrating tidal flat.

For each of the measurement layers, the attribute table should include:

- Delta: Unique three digit delta identifier.
- MPG: Major population group.
- F\_Type: The category of a feature being measured.
- S\_Type: A designation of feature size (Primary/Secondary – Distributary, Large/ Small – Tidal Channel).
- M\_Type: A designation of feature source (Natural/Modified/Restoration)
- Date: Extracted from the aerial imagery layer.
- Year: Extracted from the aerial imagery layer.
- Observer: The name of the observer performing the measurements.
- Comment: A field where observers can enter comments.
- Length or Area: The calculated line length for polyline features or calculated polygon area for polygon features.

The protocols for aerial photography channel and habitat measurements are:

1. Add the appropriate layers to the data frame within ArcMap.
2. Polygon and polyline features should only be digitized within the delta boundary polygons, and not digitized within low density marsh features.

3. Digitize distributary polygons for channels that are formed from bifurcations of the river network, convey river discharge through the delta to saltwater, and are at least 2-3 meters wide.
  - a. Distributaries should be digitized along bankfull edge within delta boundaries. The downstream boundary location is somewhat subjective but should be placed at the location where the channel widens substantially and becomes mud flat rather than channel.
  - b. Classify distributary S\_Type as:
    - “Primary” for the channel conveying the most flow
    - “Secondary” for channels conveying less flow than the primary distributary
  - c. Classify distributary M\_Type as:
    - “Modified” where distributary is constructed or heavily modified, often with piers or docks
    - “Natural” where distributary is relatively unmodified from its natural state
    - “Restoration” where distributary has been modified as part of restoration effort.
4. Digitize tidal channels along the vegetated channel edge or the artificial bank edge (along docks, seawalls, etc...) where the connection between distributaries, tidal channels, or the delta boundary can be determined from the aerial image.
  - a. Digitize tidal channels as polygons where bankfull width is 2-3 meters or greater and channel is at least 35-meters long. Classify channel as large (S\_Type = Large). The downstream boundary location is somewhat subjective, but should be placed at the location where the channel widens substantially and becomes mud flat rather than channel.
  - b. Digitize tidal channel as polyline where bankfull width is less than 2-3 meters wide and channel is at least 35-meters long. Use *Buffer* tool to buffer channel polyline with 1-meter buffer. Append resulting polygon to the large tidal channel polygon layer and classify feature as small tidal channel (S\_Type = Small).
  - c. Classify M\_Type for each channel:
    - “Modified” where distributary is constructed or heavily modified, often with piers or docks .
    - “Natural” where distributary is relatively unmodified from its natural state
    - “Restoration” where distributary has been modified as part of restoration effort.
5. Digitize tidal channel complexes as polygons where complex tidal channel networks within mostly vegetated marshes prevent accurate delineation of channels. Polygons should include both the vegetated islands and tidal channel network. These features typically occur in the lower delta, although some maturing restoration projects—where vegetation has become mostly established, but channels have not yet fully formed—can also be digitized as tidal complexes.
6. Tidal flat polygon features should be digitized within large unvegetated or low density vegetation marsh surfaces that occur interior of the delta boundaries.
  - a. Tidal features smaller than 2-3 meters in wetted or bankfull width should not be digitized within interior of a tidal flat, as larger features usually represent an excavated or pre-dike channel feature within the restoration project area.
  - b. Tidal flats and features within them should be classified as Restoration within M\_Type field when they appear to have been created as part of a restoration project.

## Tidal Channel Edge Habitat Length

Given that we digitized tidal channel polygons, and that juvenile fish are known to primarily use the edges of distributary and tidal channels (Beamer et al. 2005), we also calculated channel perimeters from channel polygons to derive an estimate of edge habitat length within each delta.

The GIS layers needed to calculate tidal channel edge habitat length are: 1) the delta polygon layer with unique Delta and MPG identifier, and 2) delta tidal channel features polygon layer.

The protocols for calculating tidal channel edge habitat length are:

1. Add the appropriate layers to the data frame within ArcMap.
2. Using *Dissolve*, dissolve all tidal channel features by channel feature type.
3. Create Perimeter field within tidal channel features polygon layer.
4. Using *Calculate Geometry*, calculate perimeter for each of layers' polygons in meters.
5. Using *Summarize* function on Delta field, summarize Perimeter field for tidal channel features layer and add resulting table to the data frame.
6. Join resulting table to the delta boundary layer by Delta.
7. To calculate tidal channel edge habitat length for MPG, first calculate total length of tidal channel edge habitat within each MPG. Using the *Summarize* function on the MPG field, summarize the Perimeter field for tidal channel features layer and add resulting table to the data frame.
8. Join resulting tidal channel edge habitat table by MPG.

## Tidal Channel Length

The GIS layers needed to calculate tidal channel length are: 1) the delta polygon layer with unique Delta and MPG identifier, and 2) a tidal channel features polygon layer.

The protocols for calculating tidal channel length are:

1. Add the appropriate layers to the data frame within ArcMap.
2. Using *Dissolve*, dissolve all tidal channel features by channel feature type.
3. Using *Definition Query*, parse out distributary and tidal channel features. Tidal flats and tidal complexes are excluded as their polygon shapes make it difficult to calculate clear path of flow within them.
4. Using *Create Centerline* tool within ET GeoWizards, generate center flow paths from the polygons of queried tidal channel features polygon layer.
5. Create Length field within resulting tidal channel features polyline layer.
6. Using *Calculate Geometry*, calculate length for each of layers' polylines in meters.
7. Using *Summarize* function on Delta field, summarize Length field for tidal channel features polyline layer and add resulting table to the data frame.
8. Join resulting table to the delta boundary layer by Delta.

9. To calculate tidal channel length by MPG, first calculate total length of tidal channel within each MPG. Using the *Summarize* function on the MPG field, summarize Length field for tidal channel features polyline layer and add resulting table to the data frame.
10. Join resulting tidal channel length table by MPG.

## Tidal Channel Node Density

The GIS layers needed to calculate tidal channel length are: 1) the delta polygon layer with unique Delta and MPG identifier, and 2) a tidal channel features polyline layer.

The protocols for calculating tidal channel node density are:

1. Add the appropriate layers to the data frame within ArcMap.
2. Using *Export Nodes* tool within ET GeoWizards, generate nodes from the polyline intersections of tidal channel features polyline layer.
  - a. Connections with channels modified for industrial purpose were excluded from the node density calculations.
3. Create Count field within resulting tidal channel features nodes layer.
4. Using *Definition Query*, parse out Primary Distributary feature type (S\_Type) within tidal channel layer. The density of nodes should be calculated based on the total length of primary distributary channel within each delta, much like a side-channel node density calculation for large rivers.
5. Using *Summarize* function on Delta field, summarize Length field of queried tidal channel layer and Count field of tidal channel node layer and add resulting tables to the data frame.
6. Join resulting tidal channel and tidal channel node tables to floodplain layer by Delta.
7. To calculate tidal channel node density for each delta, create a new field and using *Field Calculator* divide number of tidal channel nodes by primary distributary length.
8. To calculate tidal channel node density by MPG, first calculate total length primary distributary channel and total count of tidal channel nodes within each MPG. Using the *Summarize* function on the MPG field, summarize Length field for queried tidal channel layer and Count field for tidal channel node layer and add resulting tables to the data frame.
9. Join resulting tidal channel and tidal channel node tables by MPG.
10. To calculate tidal channel node density for each MPG, create a new field and using *Field Calculator* divide number of tidal channel nodes by primary distributary channel length.

## Area of Overwater Structures

We define overwater structures as human-built structures that shade out inter-tidal zones in the nearshore up to 200 meters inland of the shoreline or visible high-water mark. Overwater structures include docks, piers, marinas (including boats), boat rails, bridges, buoys and floats, log booms, and aquaculture facilities (e.g., net pens, clam and oyster cages). Structures identified as fill are treated as separate features because they have different ecological impacts than the shading of overwater structures and they can be challenging to identify from aerial imagery. Fill structures were not inventoried in our digitizing of overwater structures.

Two layers are required for this analysis: 1) the aerial imagery layer, 2) either an existing polygon layer containing overwater structures to updates or a new polygon layer to contain overwater structures. Auxiliary information may also be useful in distinguishing fill and overwater structures, such as the oblique shoreline photos (e.g., [Washington State Department of Ecology Coastal Atlas](#)).<sup>1</sup> The overwater structure attribute table includes:

- OWS\_ID: each feature is marked with overwater structure ID. There may be structures with the same ID if they are the same structure but changed in size or position over time.
- AREA\_M: Area in square meters
- Perimeter
- Structure: Type of structure (Table 8).
- Decking: Complete, Partial, or None. Documents the degree of shading of the structure.
- Building: Yes/No. Does the structure have a building on it?
- Boat: Yes/No. Does the digitized area include a boat?
- Complexity: This column should note more detail on the structure type.
- Observer: Cartographer's last name.
- Img\_Source: Data source of imagery used.
- County: WA state county name
- GNIS\_WC\_NM: Geographic Names Information System\_watercourse\_name. GNIS is the federal and national standard for geographic nomenclature.
- Digitized: The date the feature was first digitized.
- Img\_Year: The year of the orthophoto from which the feature was first digitized for the first time.
- D\_LC: percent urban land cover in adjacent shoreline segment
- F\_LC: percent forest land cover in adjacent shoreline segment
- Ag\_LC: percent agriculture land cover in adjacent shoreline segment
- LCC: the dominant land cover class of adjacent shoreline segment
- MarinBasin: Marine Basin includes; North Puget Sound, Whidbey Basin, Hood Canal, Strait of Juan de Fuca, and South Central Puget Sound
- MBarea\_km: Area of Marine Basin in square kilometers
- Presence and Absence columns observed by year (2002\_2006, 2013\_2016): 0 = absent, 1 = present.

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<sup>1</sup> <https://fortress.wa.gov/ecy/coastalatlantools/Map.aspx>

The protocols for measuring overwater structure area are:

1. Add the appropriate layers to the data frame within ArcMap.
2. Convert all layers to the same projection.
3. For either an existing overwater structure layer or a new one, create a column headed by the year(s) the new observations will be made to note presence and absence of structure
4. For new structures: using ArcGIS editing tool bar in ArcMap, digitize a contiguous area of each overwater structure up to 200m inland edge and indicate: structure type (Table 8), decking condition (Partial or Complete), presence of a building or not, presence of a boat, observer last name, complexity (Table 8), date digitized, year of the imagery used, and presence/absence of the OWS in observation year(s) column. If a structure's perimeter is not clear using Aerial imagery or the oblique shoreline photos, or there are other questions concerning the structure, mark 'ground truth' in the comments section.
5. Making edits to existing overwater structures:<sup>2</sup>
  - a. If a structure is digitized in previous years, but not visible in current imagery, mark it as not-present "0" for the current year or observation period.
  - b. If there is significant error in the size or position of an overwater polygon and it is confirmed that it was originally digitized incorrectly, re-digitize the structure by either editing the existing polygon or create a new shape with same OWS\_ID (Figure 16).
6. Digitize Dock/Pier structure using the following criteria:
  - a. For private docks, digitize structure only, excluding boats (Figure 17).
  - b. Within marinas or marina-like dock structures, include boats and boat spaces (Figure 18).
7. Digitize bridges and culverts within 200 meters of the shoreline if they are located over a waterway and there is evidence of water exchange:
  - a. In locations where there appears to be no water exchange, do not digitize a polygon (Figure 19).
8. Digitize Boat Rails and note whether their decking is partial or complete (Figure 20). Boat rails that are complete are classified as 'Boat Ramp' in the complexity column (note these are structures that are not fill).
9. Digitize Buoys and Floats, and classify structure type as "Buoy/Float".
10. Digitize aquaculture structures including net pens, oyster cages, and clam cages, and classify structure type as "Aquaculture" (Figure 21).
11. Digitize log booms by placing a polygon around contiguous area of the boom, and classify structure type as "Log boom". (Figure 22).

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<sup>2</sup> For the Puget Sound study area we started with a layer created from 2002–06, made available by the Washington State Department of Natural Resources at [http://geo.wa.gov/datasets/435072fe451e43ea93144e3ec08e93e5\\_2](http://geo.wa.gov/datasets/435072fe451e43ea93144e3ec08e93e5_2).

Table 8. Overwater structure types.

Structure Type	Structure Complexity
Dock/Pier	Smalldock, Largedock, Marina, Building, Pier, Pilings, Staircase
Bridge	Bridge, Culvert, Unknown
Boat Rail	Boat Rail, Boat Ramp
Buoy/Float	Buoy/Float
Aquaculture	Net pen, Shellfish, Unknown
Log Boom	Log Boom



Figure 16. Example of a Marina feature where the original structures were not properly aligned or digitized uniformly.



Figure 17. Example of digitized features where the original structures included boats and updates have been made to exclude boats to reduce variability.



Figure 18. Example of overwater structure Marina category. For consistency, the polygon includes boats docked at the marina as well as empty slips (we assume most slips have a boat in them most of the time).



Figure 19. Example of digitized OWS where there is water exchange and where there is not visible water exchange.



Figure 20. Example of digitized boat rail category with partial decking.



Figure 21. Example of digitized net pens within the aquaculture category.



Figure 22. Example of digitized log boom.

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## Appendix A

### Small Tidal Channels and Tidal Channel Complexes

We also carried out a pilot small tidal channel census for the Snohomish River estuary to quantify the relationship between small tidal channels and tidal channel complex area. All small tidal channels (less than 2-3 meters in width) were digitized as polylines within the tidal channel complex polygons (Figure A-1), and total small tidal channel length was regressed against tidal channel complex area (Figure A-2). There is a strong positive linear relationship between small tidal channel length and tidal channel complex area, which suggests that polygons can be used to quantify tidal channel habitat within these tidal channel complexes without having to digitize all tidal channel features. However, additional samples should be taken in other deltas to determine if the relationships are similar in strength and magnitude.

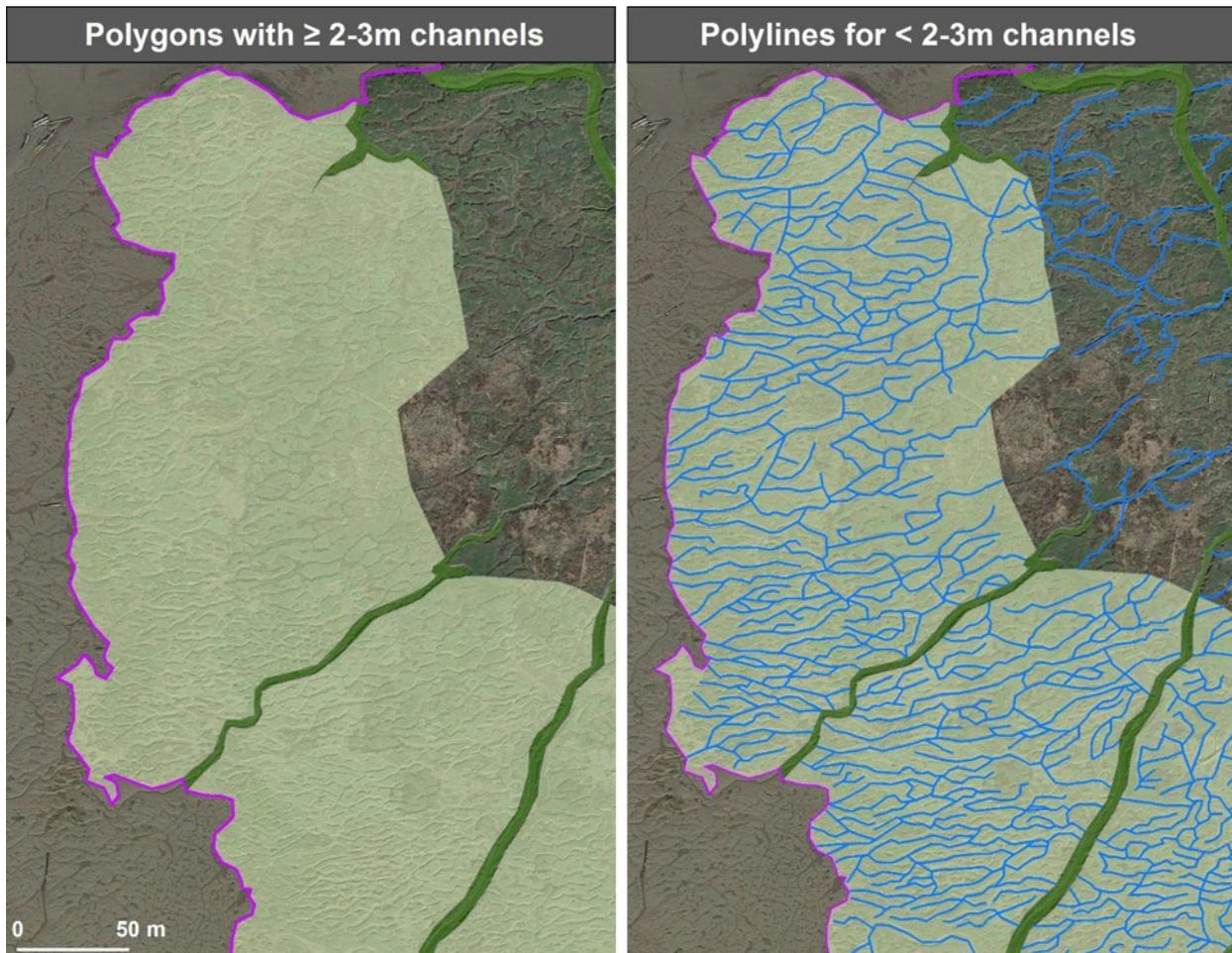


Figure A-1. Example of tidal channel complexes in the Snohomish River estuary with polygons of tidal channel complexes and large tidal channels ( $\geq 2-3$  meters bankfull width) on the left, and small tidal channels ( $< 2-3$  meters bankfull width) digitized as polylines within the tidal channel complexes on the right.

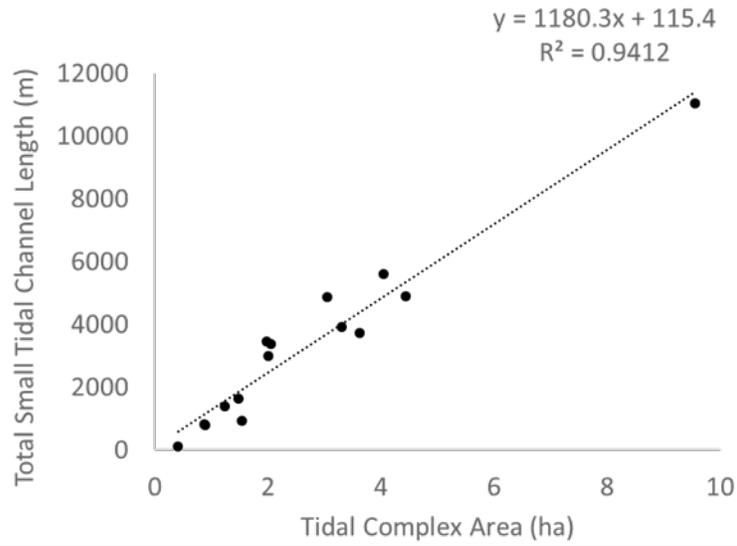


Figure A-2. Relationship between tidal channel complex area for tidal channel complexes in the Snohomish River estuary and total small tidal channel length within each tidal channel complex polygon. Each point represents a tidal channel complex polygon within the Snohomish River estuary and the total length of small tidal channel features digitized within each polygon.



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